MEASURING THE PRICE RESPONSIVENESS OF RESIDENTIAL WATER

DEMAND IN CALIFORNIA'S URBAN AREAS

A Report Prepared for the California Department of Water Resources[*]

by

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ABSTRACT

To assess the potential of price policy as a residential water resource management tool, an econometric model of residential demand is formulated and estimated. This econometric model explicitly incorporates alternative demand side management (DSM) policy instruments, endogenous block pricing schedules, and a Fourier series to separately capture the effects of seasonality and climate on residential demand. The analysis relies on agency-level cross-section time series data for eight water agencies in California representing approximately 7.1 million people or 24% of the total population. The estimation results suggest that price is a moderately effective instrument in reducing residential demand within the observed range of prices. In addition, estimation results indicate that alternative DSM policy instruments (such as public information campaigns, retrofit subsidies, water use restrictions and rationing) reduced residential water usage.

I.   INTRODUCTION

Increased reliance on demand side management (DSM) policies as an urban water resource management tool has stimulated significant discussion among economists, water utility managers and policy makers. While economists generally advocate residential water prices that reflect marginal costs as a means of reducing demand during periods of limited water supply availability, others argue that residential demand is price inelastic and thus price is a relatively ineffective DSM policy. This argument rests on both economic theory and empirical evidence which indicate that residential water demand is expected to be relatively price inelastic.[1, 2]   Yet, the argument that residential consumers do not respond to higher prices because demand is price inelastic is seriously flawed for at least two reasons. First, since a market demand curve for most functional forms will be inelastic in some price ranges and elastic in others, reference to a demand curve as either inelastic or elastic must be made in relation to a specific range of prices. Second, some policy makers have erroneously equated price inelasticity with no price responsiveness. The description of residential demand as price inelastic is a technical definition; it simply means that a one percentage increase in price results in a less than one percentage decrease in consumption. In other words, consumers respond to higher prices, but at a rate less than proportionate to the price increase. In addition, some advocates of non-price policy have argued that the "the use of price as an allocation mechanism is constrained by the fact that water is generally regarded as a basic necessity, even a right, not an economic good" (Berk et al., 1980).

The problem facing water utility managers and policy makers is a lack of adequate

information to determine the potential performance of price policy in their communities.

While water utility managers frequently adopt a combination of price and alternative

DSM policy instruments, particularly during periods of limited supply availability, most

previous economic analyses of residential water demand have ignored the effect of

alternative DSM policies.[3] "Non-price" DSM policy instruments – those that do not

affect the price of water -- include public education campaigns, rationing, water use

restrictions and subsidies for adoption of more water efficient technologies. Failure to

account for the influence of non-price DSM policies on demand when both price and non-

price policies have been implemented may result in an overestimate of the price

responsiveness of water demand.

   To assess the potential of price policy to reduce demand, an econometric model of

residential demand for water is formulated and estimated in a Two Stage Least Squares

(2SLS) estimation framework. This econometric model explicitly incorporates

alternative non-price DSM policies, endogenous block pricing schedules, and a harmonic

model to separately capture the effects of seasonality and climatic variability on demand,

improving upon earlier specifications (Nieswiadomy, 1992; Nieswiadomy and Molina,

1989; Moncur, 1987). The analysis relies on agency-level cross sectional monthly time

series data over an eight-year period for eight urban communities in California,

representing 7.1 million people.

II. DSM POLICIES IN URBAN CALIFORNIA

To assess the relative performance of price policy to reduce aggregate demand, this research takes advantage of experience with residential DSM programs implemented in California during the 1989-96 period. This period includes California's statewide drought, which persisted with varying degrees of intensity between 1985 and 1992, allowing examination of both price and alternative non-price policy instruments. Data collection efforts were conducted in eight urban water agency service areas covering 24 percent of California's population (7.1 million people). The eight agencies include: San Francisco Water Department (SFWD), Marin Municipal Water District (MMWD), Contra Costa Water Agency (CCWA), East Bay Municipal Utility District (EBMUD), City of San Bernardino (SBERN), City of Santa Barbara (SBARB), Los Angeles Department of Water and Power (LADWP), and City of San Diego (SDIEGO). These areas were selected for a number of reasons including varying hydrological conditions, geographical dispersion, and experience under different DSM policy regimes.

Table 1 shows average single family monthly water use for the 1989-96 period. There is significant variability in average water usage across agencies during the study period, ranging from approximately six hundred cubic feet (hcf) per month in San Francisco Water Department's (SFWD) service area to approximately 25 hcf per month in the City of San Bernardino (SBERN). This variability reflects, in part, such differences as average residential landscaped areas and climatic conditions. In San Francisco, most water use occurs indoors as high density housing limits potential landscaped area and concomitant irrigation. Average monthly water usage trended downward over the period for nearly all of the agencies. However, the reductions in use

varied significantly between agencies on both an absolute and relative basis. These

reductions are particularly pronounced during the 1990-92 period, presumably due to

drought induced reductions in water supply availability and associated price and

alternative non-price DSM programs.

TABLE 1: Average Single Family Residential Monthly Water Use by Agency: 1989-96

Year	SFWD	CCWA	SBARB	LADWP	MMWD	SBERN	SDIEGO	EBMUD
……………………………. HCF[1]…………………………….								
1989	6.53	15.28	14.65	19.11	10.48	24.97	14.50	10.68
1990	6.49	15.04	7.31	18.30	10.28	24.35	13.59	10.92
1991	5.53	10.10	7.29	14.48	7.58	22.18	10.83	9.41
1992	5.91	11.90	8.96	15.23	8.62	21.8	11.73	10.03
1993	6.31	12.67	9.78	15.51	9.23	22.14	11.73	10.78
1994	6.68	12.86	10.48	16.28	9.73	22.56	12.00	11.12
1995	6.61	12.82	10.51	16.07	9.90	22.90	11.88	11.13
1996	6.79	13.34	11.12	17.51	10.48	24.67	13.07	11.51
1989-96 Avg.	6.36	13.00	10.01	16.56	9.54	23.20	12.42	10.70

[1] One hundred cubic foot (hcf) equals 756 gallons.

Table 2 provides a summary of average marginal prices paid and type of pricing schedule

in effect by agency. Average marginal water prices ranged from a low of $.49 per hcf in

the City of San Bernardino (SBERN) to a high of $3.78 per hcf in Marin Municipal Water

District's (MMWD) service area. These differences reflect, in part, differences in water

supply availability. For example, the city of San Bernardino lies at the foot of the

mountains and has substantial groundwater reserves, while Marin Municipal Water

District has coped with varying degrees of limited supply availability since the 1970s.

Marginal prices trended upward over the 1989-96 period, however, the magnitude of

price increases varied by agency. Both uniform (UR) and increasing block (IB) rate

schedules were observed across sample agencies and over time. Under uniform rates –

the rate schedule most frequently employed -- each household pays a fixed price per hcf.

Under increasing block pricing schedules, the per hcf price depends on the total amount

of water consumed. In general, marginal prices were higher in agencies where increasing

block pricing schedules were in effect.

Beyond changes in residential prices, all of the agencies adopted at least one type

of non-price DSM policy to induce households to use water more efficiently. Table 3

provides a summary of key non-price DSM policies implemented by each agency during

the 1989-96 period. Due to the aggregate level of analysis, only those policies expected

to significantly influence demand are included in the table. DSM policies are aggregated

into six basic types of policies (Renwick, 1996). The most popular types of non-price

DSM policies implemented during the study period were voluntary measures, including

public information campaigns (INFO) and subsidies to encourage adoption of more water

efficient technologies (RETRO, REBATE). Public information campaigns (INFO) alert

households to shortages, attempt to motivate more water efficient behavior and provide

information on means to reduce usage. Effective public information campaigns shift

households' demand curves by altering tastes and preferences. Subsidies to encourage

adoption of water efficient technologies represent another means of shifting the

household water demand curve by improving the technical efficiency of water using

fixtures. Subsidy programs represented include ultra low flow toilet rebate programs (REBATE) and distribution of free retrofit kits (RETRO). Retrofit kits usually include a low flow showerhead, tank displacement devices and dye tablets for leak detection, represent another DSM policy instrument.

TABLE 2: Average Marginal Prices and Type of Pricing Schedule[1] by Agency: 1989 - 96

Year	SFWD	CCWA	SBARB	LADWP	MMWD	SBERN	SDIEGO	EBMUD
				$ per hcf				
1989	$.59^{UR}$	1.01^{UR}	$1.30^{UR, IB}$	1.02^{UR}	$1.66^{UR, IB}$	49^{UR}	1.04^{IB}	$.72^{UR}$
1990	$.63^{UR}$	1.00^{UR}	2.80^{IB}	1.21^{UR}	2.21^{IB}	$.60^{UR}$	1.08^{IB}	$.96^{UR}$
1991	$.81^{UR}$	1.00^{UR}	3.62^{IB}	1.13^{UR}	2.97^{IB}	$.69^{UR}$	1.06^{IB}	$.98^{UR}$
1992	$.92^{UR}$	1.68^{UR}	3.70^{IB}	1.43^{UR}	3.78^{IB}	$.72^{UR}$	1.22^{IB}	1.08^{UR}
1993	$.96^{UR}$	1.68^{UR}	3.70^{IB}	$1.61^{UR, IB}$	2.74^{IB}	$.72^{UR}$	1.32^{IB}	$1.15^{UR, IB}$
1994	1.10^{UR}	1.68^{UR}	3.70^{IB}	1.78^{IB}	2.13^{IB}	$.72^{UR}$	1.40^{IB}	1.21^{IB}
1995	1.17^{UR}	1.75^{UR}	3.63^{IB}	1.84^{UR}	2.30^{IB}	$.72^{UR}$	1.43^{IB}	1.31^{IB}
1996	1.22^{UR}	1.76^{UR}	3.50^{IB}	1.75^{UR}	2.13^{IB}	$.72^{UR}$	1.50^{IB}	1.41^{UR}
1989-96 Avg.	.93	1.45	3.24	1.47	2.49	.67	1.26	1.11
Predominant Pricing Schedule[2]	UR	UR	IB	UR	IB	UR	IB	UR

[1] *UR* means uniform or fixed per unit pricing schedules and *IB* stands for increasing block pricing schedule.
[2]   This refers to the type of pricing schedule used for the greatest percentage of month over the 1989-96 period.

The other types of DSM policies employed place direct controls on the level or nature of water use and as such are considered as mandatory policy instruments.

Rationing programs (RATION) generally allocate a fixed quantity of water to households, based on some allocation criteria, and impose penalties for exceeding the allotment such as severe marginal price penalties. Water use restrictions (RESTRICT) constitute a more precise form of rationing. Use restrictions place constraints on when certain types of water use practices can occur such as no washing down sidewalks and driveways or bans on landscape irrigation during peak evapotranspiration hours. For example, the City of Santa Barbara banned nearly all forms of irrigation during the 1990-91 period, except for drip and hand-held irrigation methods, and hired "water police" to enforce the policy. San Francisco Water Department adopted a compliance affidavit (COMPLY) program. This program required all households to file an affidavit attesting that specific water efficient devices were installed in the household. No enforcement mechanisms were employed, although households who did not file the affidavit faced higher marginal prices.

To better understand how DSM policies influence residential demand, the analysis now moves from the two-dimensional world of descriptive statistics to multivariate analysis.

TABLE 3: Overview of Key Non-Price DSM Policy Instruments by Agency: 1989-96

	Type of DSM Policy Implemented [1,2]					
Agency	INFO	REBATE	RETRO	RATION	RESTRICT	COMPLY
SFWD	X	X		X		X
CCWD	X	X	X	X		
SBARB	X	X	X		X	
LADWP	X	X	X		X	
MMWD	X	X	X			
SBERN			X			
SDIEGO	X	X	X			
EBMUD	X	X	X			

Source: Agency provided information.

[1] This does not represent an exhaustive list of DSM policies implemented. Rather, it identifies key policy instruments in effect during the 1988-96 period.

[2] Policies definitions are as follows: Public information campaigns (INFO), low flow toilet rebate programs (REBATE), distribution of free plumbing retrofit kits (RETRO), water rationing/allocation policies (RATION), restrictions on certain types of water uses (RESTRICT), and San Francisco Water Department's compliance affidavit policy (COMPLY).

III. A MODEL OF RESIDENTIAL DEMAND FOR WATER

An econometric model of residential water demand is specified and estimated to identify the reduction in aggregate demand attributable to price. The influence of alternative non-price DSM policies is also assessed. The model is composed of three basic components: price equations (two equations), climate equations (two equations) and a water demand equation. The price equations capture the influence of endogenous price effects on demand under block rate schedules since the marginal price depends on the

quantity demanded. The climate equations capture the influence of variations in climate from "normal" seasonal patterns.[4, 5] Predicted values for the price and climatic variables are used in the second stage of the analysis to help explain changes in residential water demand and to assess the relative contributions of price and non-price policies in the reduction of demand.

The model of residential water demand takes the following form:

Price Equations

$$lnMP_{it} = \sum \boldsymbol{a}^{mp} lnZ_{it}^{mp} + e_{it}^{mp} \tag{1}$$

$$lnD_{it} = \sum \boldsymbol{a}^{dw} lnZ_{it}^{dw} + e_{it}^{dw} \tag{2}$$

Climate Equations

$$lnDTEMP_{it} = \boldsymbol{g}_0^{tp} + \sum_{j=1}^{6}\left\{\boldsymbol{g}_{,j}^{tp}\sin\left(\frac{2\boldsymbol{p}j}{12}\right) + \boldsymbol{g}_{,j}^{tp}\cos\left(\frac{2\boldsymbol{p}j}{12}\right)\right\} + e_{it}^{tp} \tag{3}$$

$$lnDPREC_{it} = \boldsymbol{g}_0^{pr} + \sum_{j=1}^{6}\left\{\boldsymbol{g}_{,j}^{pr}\sin\left(\frac{2\boldsymbol{p}j}{12}\right) + \boldsymbol{g}_{,j}^{pr}\cos\left(\frac{2\boldsymbol{p}j}{12}\right)\right\} + e_{it}^{pr} \tag{4}$$

Water Demand Equation

$$lnW_{it} = \left(\begin{array}{l} \boldsymbol{b}_0 + \boldsymbol{b}_1 ln\hat{MP}_{it} + \boldsymbol{b}_2 ln\hat{D}_{it} + \boldsymbol{b}_3 lnINC_{it} + \boldsymbol{b}_4 INFO_{it} + \boldsymbol{b}_5 RETRO_{it} + \\ \boldsymbol{b}_6 REBATE_{it} + \boldsymbol{b}_7 RATION_{it} + \boldsymbol{b}_8 RESTRICT_{it} + \boldsymbol{b}_9 COMPLY_{it} + \\ \boldsymbol{b}_{10} LIRR_{it} + \boldsymbol{b}_{11} HIRR3_{it} + \boldsymbol{b}_{12} ln\hat{TEMP}_{it} + \boldsymbol{b}_{13} ln\hat{PREC}_{it} + \boldsymbol{b}_{14} LOT_{it} \\ + \boldsymbol{b}_{15,j}\sin\left(\frac{\boldsymbol{p}j}{6}\right) + \boldsymbol{b}_{16,k}\cos\left(\frac{\boldsymbol{p}k}{6}\right) + e_{it};\ j = 1,..,5\ \text{and}\ k = 1,..,6 \end{array}\right) \tag{5}$$

where

$$e_{it} = \boldsymbol{r} e_{it-12} + u_{it}$$

$$lnZ_{it}^{mp} = \left(lnP1_{it-1}, lnP2_{it-1}, lnP3_{it-1}, lnINC_{it}, lnHH_{it}, lnLOT_{it}\right)$$

$$lnZ_{it}^{dw} = \left(lnP1_{it-1}, lnP2_{it-1}, lnP3_{it-1}, lnINC_{it}, lnHH_{it}, lnLOT_{it}, BLOCK_{it}, lnD_{it-1}\right)$$

$$ln\,\hat{\text{TEMP}}_{it} = \hat{e}_{it}^{tp} = lnDTEMP_{it} - lnD\hat{T}EMP_{it}$$

$$ln\,\hat{\text{PREC}}_{it} = \hat{e}_{it}^{pr} = lnDREC_{it} - lnDP\hat{R}EC_{it}$$

Variable definitions are presented in Table 4.

The marginal price and difference variable equations, *lnMP* and *lnD*, represent the first two of the five equation demand system (Equations 1 and 2). In the second stage of the analysis, the marginal price variable (*MP*) captures the effect of intermarginal price changes on demand, while the difference variable (*D*) captures the effect of intramarginal rate changes on water demand under increasing block price schedules, in accordance with the "Taylor-Nordin" specification.[6] Following Nieswiadomy and Molina (1989), the set of instrumental variables, (*lnZ*), includes the lagged marginal price for each block of the rate schedule and selected socioeconomic variables.[7] Fitted values for the marginal price and difference variables are used in the second stage of analysis to help explain changes in residential water demand.

TABLE 4: Variable Definition

Indicator	Name/Unit	Description
W_{it}	Water Use (hcf)	Average SFR household monthly water use
MP_{it}	Marginal Price ($/hcf)	Marginal price of water
D_{it}	Difference ($)	Difference variable[1]
$INFO_{it}$	Public Information Dummy	$INFO_{it}$ = 1 for agency i and periods t when policy was in effect = 0 otherwise.
$RETRO_{it}$	Retrofit Kit Dummy	$RETRO_{it}$ = 1 for agency i and periods t when policy was in effect = 0 otherwise.
$REBATE_{it}$	Low Flow Toilet Rebate Dummy	$REBATE_{it}$ = 1 for agency i and periods t when policy was in effect = 0 otherwise.
$RATION_{it}$	Water Rationing Dummy	$RATION_{it}$ = 1 for agency i and periods t when policy was in effect = 0 otherwise.
$RESTRICT_{it}$	Water Use Restrictions Dummy	$RESTRICT_{it}$ = 1 for agency i and periods t when policy was in effect = 0 otherwise.
$COMPLY_{it}$	Water Affidavit Dummy	$COMPLY_{it}$ = 1 for agency i and periods t when policy was in effect = 0 otherwise.
$LIRR_i$	Limited Irrigation Dummy	$LIRR_{it}$ = 1 for agency i, if expect no or low irrigation = 0 otherwise.
$HIRR_i$	Significant Irrigation Dummy	$HIRR_{it}$ = 1 for agency i, if expect rel. high irrig. = 0 otherwise.
HH_i	People per Household	Average number of people per household in agency i
INC_i	Income ($1,000)	Average monthly gross household income
LOT_i	Lot Size (1,000s Ft^2)	Average household lot size
$BLOCK_{it}$	Block Pricing Dummy	$BLOCK_{it}$ = 1 for agency i and periods t when block pricing schedule in effect = 0 otherwise.
$DPREC_{it}$	Precipitation	Deviation of cum. monthly rainfall from historic mean
$DTEMP_{it}$	Avg. Max. Air Temp.	Deviation of avg. max. daily air temp. from historic mean
$Cos(\lambda_k t)$	Cosine harmonic	$\lambda_k = 2\pi k$; k = 1,..,6 (annual…bi-monthly harmonic)
$Sin(\lambda_k t)$	Sine harmonic	$\lambda_k = 2\pi k$; k = 1,…6 (annual…bi-monthly harmonic)
$P(X)_{it}$	Marginal Price Instruments ($)	Marginal price in block X of agency i's pricing schedule in period t, where X = 1, 2, 3

i = 1,…8 agencies; t = 1,..96 months

[1] The difference variable (D_{it}) is defined as the difference between what a consumer would have paid if all units were purchased at the marginal price and the amount paid under the block pricing schedule.

$$D = P_m Q - \left(\sum_{l=1}^{m-1} P_l Q_l + P_m \left(Q - \sum_{l=1}^{m-1} Q_l \right) \right),$$ where m identifies the block in the price schedule in

which consumption occurs, P_l is the marginal price in the lth block, Q_l is the threshold quantity in the lth block and Q is the total quantity demand and is contained in the mth block. Time and agency subscripts are dropped here to reduce cumbersome notation.

Equations 3 and 4 are used to capture and separately identify the effects of climate and seasonality on demand following Chesnutt and McSpadden (1991). The climatic variables include maximum daily air temperature (*DTEMP*) and cumulative monthly precipitation (*DPREC*). Both variables are expressed in deviation form from their historical mean.[8] Fitted residuals from these climate equations are used in the demand equation in the second stage of analysis to represent the effect of deviations in maximum air temperature and precipitation from "normal" seasonal patterns. In other words, they capture aberrations in climate from anticipated seasonal patterns.

Following Lyman (1992), Chesnutt and McSpadden (1991) and others, the water demand equation (Equation 5) is specified as a logarithmic functional form. The demand equation includes both the fitted marginal price ($ln\hat{MP}$) and difference ($ln\hat{D}$) variables. Under increasing block pricing schedules, the difference variable acts as a lump sum income transfer and is expected to positively correlate with water use.

Non-price DSM polices are also expected to influence water demand. Dummy variables representing the six types of DSM policies implemented – as described in Table 3 – are included in the demand equation and are expected to negatively correlate with water use. These dummy variables include: public information campaigns (*INFO*), distribution of free retrofit kits (*RETRO*), low flow toilet rebate programs (*REBATE*), water rationing policies (*RATION*), water use restrictions (*RESTRICT*) and San Francisco's compliance affidavit policy (*COMPLY*).

Household characteristics are also expected to influence demand. Median household income (*lnINC*) for each agency's service area is included in the model and expected to positively correlate with demand. A variable measuring lot size (*lnLOT*) is

also included in the demand equation. Households with larger lots are expected to have higher discretionary outdoor water usage, all other factors held constant. In addition, fixed effects irrigation dummy variables (*LIRR* and *HIRR*) are incorporated into the demand equations to allow for expected differences in outdoor water use patterns by agency. Although larger lots tend to positively correlate with higher water usage due to landscape irrigation demands, departures from this pattern exist. For example, the average lot size in Municipal Water District's service area are relatively large, however, most household maintain native landscape with very limited or no irrigation requirements. In contrast, while average lot sizes in the LADWP service area are moderately sized, outdoor water usage is expected to be higher due to the preponderance of swimming pools and other outdoor water using activities. These fixed effect dummy variables were selected in lieu of agency-specific dummies for reasons of model parsimony given that estimation issues associated with collinearity among explanatory and agency-specific dummy variables existed.

Seasonality in residential water demand is captured through a harmonic model, consisting of a Fourier series of sine and cosine terms of various harmonic frequencies. Rather than truncate the Fourier series *a priori*, all six harmonics are initially included and then those which do not contribute "sufficiently" to explanatory power of the model are removed (Doran and Quilkey, 1972). To capture the influence of changes in historical climatic patterns, fitted residuals from the first stage air temperature ($ln\,\hat{\text{TEMP}}_{it} = \hat{e}_{it}^{tp}$) and precipitation ($\hat{\text{PREC}}_{it} = \hat{e}_{it}^{pr}$) equations (Equations 3 and 4) are included in the demand equation. Air temperature is expected to positively correlate with water demand, while the precipitation is expected to negatively correlate.

As detailed above, the model is estimated using a 2SLS estimation procedure to account for both the endogeneity of the marginal price and difference variables under increasing block pricing schedules and to seasonally adjust climatic variables. In the first stage, the price and climatic equations (Equations 1 - 4) are estimated. A classical additive disturbance term with zero expectation and finite variance is added to each equation and is estimated using OLS. Fitted values are used in the second stage of the estimation procedure.

In the second stage, the water demand equation (Equation 5) is estimated using nonlinear least squares (NLS) with predicted values from the price and climatic equations ($ln\ \hat{MP}$, $ln\ \hat{D}$, $ln\ \hat{TEMP}$, $ln\ \hat{PREC}$). The estimation procedure accounts for expected groupwise hetereoscedasticity (due to anticipated differences in water use variability between agencies) and a twelfth order autoregressive disturbance, AR(12), process.[9, 10]

IV. DATA

Agency-level mean monthly single family water use and cost data were obtained from each agency for the eight-year (1989-96) period.[11] Information relating to non-price DSM policies were collected. Socioeconomic data such as median household income and number of people per household were estimated from the 1990 U.S. Bureau of the Census Population and Housing Summary. These estimates were based on aggregation of census tracts within each agency's service area.[12] In addition, average lot sizes for each agency were estimated based on the Sacramento Area Council of Governments' "1990 Census Geographic Areas Reference List." [13]

Cummulative monthly precipitation and average monthly maximum daily air temperature data were compiled by the Western Regional Climate Center. Both monthly data for the 1989-96 period as well as the long-term historical data were compiled. For each agency a pooled measurement for each climatic variable was constructed based on actual measures from weather stations in each area.[14] The pooled approach for climatic variables was selected to increase measurement precision, given potential variability in the quality and availability of climatic variables across each agency's service area.

V. RESULTS

The estimation results for the water demand equation, shown in Table 5, indicate good model performance.[15] All coefficients generally exhibit expected signs and are statistically significant. The results appear robust to changes in specification (see Appendix Table A.3). The adjusted R-square for the two stage least squares (2SLS) model, which includes predicted values for price and difference variables and seasonally adjusted climatic variables, is .91.

The signs and statistical significance of the climatic, socio-economic and structural variables also demonstrate the model's robust performance. The estimated coefficient on the income variable ($lnINC$) and predicted increasing block price implicit income subsidy variable ($ln\hat{D}$) – known as the difference variable – exhibit the anticipated positive effect of household water use. The magnitude of the income variable implies that a 10 percent increase in income will increase average household monthly water demand by 2.5 percent. This income elasticity of demand is comparable with other

residential water demand studies (Howe and Linaweaver (1967), Jones and Morris (1984), and Nieswiadomy (1992)).[16]

The estimated coefficient on the lot size (*lnLOT*) variable, a proxy for landscaped area, is positive and statistically significant. The larger the landscaped area, the greater the demand for water. The magnitude of the estimated coefficient implies a 10 percent increase in lot size square footage will result in a 2.7 percent increase in water demand on average, all other factors held constant.

The estimated coefficient on the predicted de-seasonalized maximum air temperature variable is positive and statistically significant, suggesting that higher than average maximum daily air temperatures increase the demand for water. As described above, seasonality is captured in the model through a Fourier series of sine and cosine terms of various harmonic frequencies. The estimated coefficients on the annual frequency sine and cosine terms were statistically significant. Higher frequency terms were dropped from the final specification due to their minimal change in explanatory power associated with their omission following Doran and Quilkey (1972).[17] These results provide support for Chesnutt and McSpadden's (1991) argument that "because the lower frequencies tend to explain more of the seasonal fluctuation, the higher frequencies can be omitted with little predictive loss."

TABLE 5: Water Demand Estimation Results

Variable	Est. Coefficient _Standard Error_
Intercept	2.61 _0.16_***
$ln\ \hat{MP}$	-0.16 _0.03_***
$ln\ \hat{D}$	0.01 _0.02_
INFO	-0.08 _0.02_***
REBATE	-0.004 _0.02_
RETRO	-0.09 _0.02_***
RATION	-0.21 _0.03_***
RESTRICT	-0.34 _0.04_***
COMPLY	0.003 _0.03_
lnINC	0.25 _0.10_**
lnLOT	0.27 _0.03_***
HIRR	0.53 _0.05_***
LIRR	-0.30 _0.04_***
$ln\ \hat{TEMP}$	0.45 _0.11_***
$ln\ \hat{PREC}$	-0.01 _0.01_
SIN1	-0.28 _0.02_***
COS1	0.10 _0.02_***
RHO	0.58 _0.03_***
R^2 (Adj)	.91

*** = significant at the .01 level, ** = significant at the .05 level
* = significant at the .10 level

The coefficient on the marginal price of water ($ln\ \hat{MP}$) is, as expected, negative and statistically significant, as shown in Table 5. The estimated own-price elasticity of demand equals -.16, implying a 10 percent increase in price will reduce the aggregate quantity demanded by 1.6 percent. Isolating seasonal own-price elasticities indicated that the own-price elasticity of demand for the summer months (June - August) equals -.20.[18] These own-price elasticity estimates are within the order of magnitude of previous studies. These estimates range from -.15 to -.52 (Nieswiadomy (1992); Nieswiadomy and Molina (1989), Billings (1987), Moncur (1987), and Agthe et al. (1986)). The estimated own-price elasticities are slightly less than those previously estimated for urban areas in California, which range from -.22 to -.37 (Renwick (1996), Renwick and Archibald (1998) and Berk et al. (1980)) perhaps due to the exclusion of alternative DSM policy variables (Berk et al., 1980) and the significantly larger range of marginal prices (Renwick (1996) and Renwick and Archibald (1998)) in these other studies. In interpreting these estimation results, particularly for policy purposes, it is important to remember that the estimated own-price elasticities are only valid within the region of observed marginal prices which ranged from $.47 to $4.25.

Estimation results also indicate that alternative DSM policy instruments had a measurable effect on aggregate water demand. The estimated coefficients on the public information campaigns (*INFO*), retrofit subsidies (*RETRO*), water rationing (*RATION*) and water use restrictions (*RESTRICT*) policy dummies were all negative and statistically significant. The magnitude of the estimated coefficients indicated that more stringent mandatory policies, such as use restrictions, reduced demand more than voluntary measures, such as public information campaigns. While these results provide further

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empirical evidence regarding the effectiveness of alternative DSM policy instruments, they must be interpreted with caution due to the aggregate nature of the data and definition of policy instruments. The remaining two DSM policy dummies (*REBATE* and *COMPLY*) were not statistically significant, probably as a result of aggregating the policies across several agencies and definition of when the policy was in effect.[19] These results do not imply that these later two types of policies (*REBATE* and *COMPLY)* are ineffective DSM instruments, rather that they did not have a measurable influence on demand in this study. They do suggest, however, that the definition of policy variables may be extremely important for accurate measurement since the nature of these types of policy instruments may vary either over time or cross-sectionally.

V. CONCLUSIONS

The goal of this research was to assess the performance of price as a water resource management tool. Aggregate single family household demand was responsive to price changes. In addition, non-price DSM policy instruments were found to reduce demand. These results suggest that both price and non-price DSM policies are relatively effective residential water resource management tools. The results also highlight the importance of accounting for the influence of both price and non-price DSM policies in analyses of residential demand and stress the need for further research focused on measuring the change in residential water demand in response to non-price policies.

APPENDIX TABLE A.1: Weather Stations by Agency

Agency	Weather Station
San Bernardino	San Bernardino
	Little Creek FTHL Blvd
Los Angeles Dept. of Water and Power	Los Angeles Civic Center
	San Pedro
	Los Angeles Airport
	UCLA
	Canoga Park/Pierce College
	Culver City
Santa Barbara	Santa Barbara
San Francisco Water Department	San Francisco Richmond
	San Francisco Mission Dolores
Marin Municipal Water District	Kentfield
	San Rafael Civic Center
Contra Costa Water Agency	Concord Wastewater
	Matinez 2 5
East Bay Municipal Water District	Richmond
	Berkeley
	Oakland Musuem
	Oakland WSOAP
	Upper San Leandro Fltr
San Diego	San Diego Airport
	Le Mesa

APPENDIX TABLE A.2: Stage One Estimation Results

Variable	Dependent Variable			
	lnMP	lnD	lnDPREC	lnDTEMP
Intercept	-0.32	0.02	-0.11	0.0037
	0.28	*0.55*	*0.02***	*0.0021***
LNP1(-1)	-0.16	-0.55		
	*0.08***	*0.23***		
LNP2(-1)	1.16	0.70		
	*0.11***	*0.35.***		
LNP3(-1)	-0.2	-0.25		
	*0.07***	*0.15***		
LNLOT	-0.04	-0.01		
	*0.007***	*0.008**		
LNHH	0.18	-0.04		
	0.2	*0.39*		
LNINC	0.05	-0.002		
	0.06	*0.12*		
BLOCK		0.07*		
		0.04		
lnD(-1)		0.82		
		*0.05***		
SIN1			0.01	-0.0028
			0.02	*0.0021*
SIN2			0.07	-0.004
			*0.02***	*0.002***
SIN3			-0.08	0.0055
			*0.02***	*0.0021***
SIN4			0.06	-0.0018
			*0.02***	*0.002*
SIN5			-0.03	-0.0049
			0.02	*0.0021***
COS1			-0.17	-0.0024
			*0.02***	*0.0022*
COS2			-0.09	0.0064
			*0.02***	*0.0023***
COS3			-0.08	0.0032
			*0.03***	*0.0022*
COS4			-0.005	-0.0027
			0.02	*0.0023*
COS5			-0.16	0.0075
			*0.02***	*0.0022***
COS6			-0.01	-0.0012
			0.02	*0.0015*
R^2 (Adj)	0.91	0.85	0.14	0.04

*** = significant at the .01 level, ** = significant at the .05 level
* = significant at the .10 level

APPENDIX TABLE A.3: Estimation Results Under Full Climatic Specification

Variable	Est. Coefficient
	Standard Error
Intercept	2.62
	0.15***
$ln\ \hat{MP}$	-0.16
	0.03***
$ln\ \hat{D}$	0.01
	0.01
INFO1	-0.08
	0.02***
REBATE	-0.003
	0.02
RETRO	-0.09
	0.02***
RATION	-0.21
	0.05***
RESTRICT	-0.34
	0.06***
COMPLY	0.003
	0.02
LNINC	0.24
	0.10**
LNLOT	0.27
	0.03***
HIRR	0.52
	0.05***
LIRR	-0.30
	0.04***
$^{ln}\hat{TEMP}$	0.44
	0.13***
$^{ln}\hat{PREC}$	-0.01
	0.01
SIN1	-0.28
	0.02***
SIN2	0.02
	0.02
SIN3	-0.01
	0.02
SIN4	-0.01
	0.02
SIN5	0.002
	0.02
COS1	0.10
	0.02***
COS2	-0.01
	0.02
COS3	-0.02

	0.02
COS4	0.004
	0.02
COS5	-0.01
	0.02
COS6	0.01
	0.01
RHO	0.58
	0.03[***]
R^2 (Adj)	

[***] = significant at the .01 level, [**] = significant at the .05 level [*] = significant at the .10 level

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Endnotes

[1] Economic theory suggests that residential water demand should be price inelastic for three reasons: (1) there exist no close substitutes for water in most of its uses; (2) the amount of money spent on water is generally a relatively small share of the typical household budget, and; (3) water is frequently demanded jointly with some other complementary good (Bach, 1980).

[2] Previous empirical studies indicating an own-price elasticity of less than negative one include Renwick and Archibald, 1998; Renwick, 1996; Nieswiadomy and Molina, 1989; Agthe et al., 1986; Billings, 1980; and Howe and Linaweaver, 1967.

[3] Exceptions include Renwick (1996) and Renwick and Archibald (1998).

[4] Normal" refers to the long-term seasonal average.

[5] Constant seasonal fluctuations in the climatic variables are filtered through a Fourier series of sine and cosine terms, as described below.

[6] Under block pricing schedules, the marginal price may convey only partial information. A simple example illustrates why this may be the case. Consider two households that demand the same amount of water and are identical in every other way, except that one faces an increasing block pricing schedule and the other faces a decreasing block pricing schedule. Although both households face the same marginal price, the total water bill and thus average price differs between the two households. As a result, the residual income available to each household after the water bill is paid differs. If this difference is large enough, otherwise identical households may behave differently.

[7] We followed Nieswiadomy and Molina (1989) in the selection of the set of instrumental variables, including marginal prices in each block together with all the socioeconomic explanatory variables. The price instruments, $lnPX_{it}$ are lagged one period to avoid contemporaneous correlation with water use under block pricing. Climatic and policy dummy variables were not included. The instrumental variables method results in consistent estimators, however, based on Brundy and Jorgenson's seminal paper (1971), future work will include these climate and policy dummy variables to improve the efficiency of the estimates.

[8] The historical mean is the long-term average based on up to 30 years of climatic data for each weather station.

[9] In the estimation procedure a consistent estimate of ρ is first obtained and then used to transform the series. The model is re-estimated under the assumption of groupwise heteroscedasticity to obtain consistent estimates.

[10] Durbin-Watson statistics were estimated to test for the possibility of first and twelveth order, , AR(1) and AR(12), autoregressive processes. The null hypotheses of no AR(1) and AR(12) were rejected at the .01 significance level. Following Wallis (1972), a joint test for AR(1) and AR(12) was estimated. The likelihood ratio test of joint AR(1) and AR(12) processes was rejected at the .01 significance level. An AR(12) process was selected given monthly annual data.

[11] Bi-monthly data were converted to monthly data where necessary.

[12] The 1990 U.S. Census median gross income data is adjusted annually with an income index based on county-level data for California.

[13] Averages for each agency were calculated based on total land in service area less publicly held land divided by number of housing units.

[14] The weather stations for each agency are shown in Appendix Table A.1.

[15] Estimation results for the stage 1 price and climatic variables are shown in Appendix Table A.2.

[16] Howe and Linaweaver (1967) estimated the income elasticity of demand as .32 for domestic water uses and .66 for irrigation demand. The estimated income elasticities of demand calculated by Jones and Morris (1984) for their three marginal price models ranged from .40 to .55. In the three marginal price models estimated by Nieswiadomy (1992) he found the income elasticity of demand to range from .28 to .44.

[17] A likelihood ratio test was performed to test the null hypothesis that the coefficients on higher order sine and cosine terms were equal to zero and was not rejected at the .01 significance level. More specifically, $-2(lnL_R - lnL_U) = -2(428.55-431.11) = 5.12$ which is Chi-Square distributed with one degree of freedom..

[18] Estimated by interacting a summer seasonal dummy variable with the marginal price variable using an equivalent model containing monthly dummy variables instead of the Fourier series to capture seasonality. The estimated coefficient on the interactive marginal price variable was -.038, resulting in an estimated own-price elasticity of -.198 for the summer months.

[19] The definition of *when* a policy went into effect and for how long can be a difficult issue from a modeling perspective. For example, many agencies had low flow toilet rebate programs for years with significantly varying degrees. Similarly, San Francisco Water Department's compliance affidavit policy (COMPLY) was in effect for over a year before the majority of households files their affidavit.